Θ production in inclusive pp scattering

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Many experiments from around the world have presented evidence for (and against) a possible exotic pentaquark spectrum. Knowledge of the existence, or non-existence, of pentaquark states is of vital importance in the search for the mechanism of quark confinement. "Can four quarks and an antiquark be confined in the same way as three quarks?" is a question of central importance.

The purpose of this talk is to discuss a particular production mechanism fo the Θ fragmentation in pp collisions at high energies

Table 1: **The Θ^+, $\Xi^{--}_{\frac{3}{2}}$, and Θ_c positive observations**

Collaboration	Reaction	Mass (MeV)
LEPS	$\gamma n \to K^+K^-n$ (^{12}C)	1540$\pm$10
DIANA (ITEP)	$K^+Xe \to K^0pXe'$	1539$\pm$2
CLAS(d)	$\gamma d \to K^+K^-pn$	1542$\pm$4
CLAS(p)	$\gamma p \to K^+K^0_s n$	1555$\pm$10
SAPHIR	$\gamma p \to K^+K^0_s n$	1540$\pm$2
HERMES	γd, $\Theta^+ \to pK_S \to p\pi\pi$	1528$\pm$3
νBC	$\nu d, Ne \to (pK^0_S)X$	1533$\pm$5
SVD-2	$pA \to (pK^0_S)X$	1526$\pm$3
COSY, Juelich	$pp \to (pK^0_S)\Sigma^+X$	1530$\pm$ 3
Dubna	$pC_3H_8 \to pK^0_S X$	1545.1$\pm$ 5
ZEUS	$ep \to (pK^0_S)X$	1522$\pm$4
NA49	$pp \to \Xi^-\pi^-(\pi^+) + X$	1862$\pm$2
H1	$ep \to D^{*-}p + X$	3099 ± 6

Table 2: Summary of null results for three possible pentaquark states.

Experiment	$\Theta^+(1540)$	$\Xi^{--}_{\frac{3}{2}}(1862)$	$\Theta_c(3100)$	Reaction
E690		NO	NO	pp
CDF	NO	NO	NO	$p\overline{p}$
HyperCP		NO		π, K, p
BaBar	NO	NO		e^+e^-
ZEUS	yes	NO	NO	ep
ALEPH	NO	NO	NO	e^+e^-
DELPHI	NO			e^+e^-
PHENIX	NO			$AuAu$
FOCUS			NO	γA
BELLE	NO		NO	KN
BES	NO			e^+e^-
SPHINX	NO			$p+N$
COMPASS	NO	NO	NO	$\mu^+(^6LiD)$
LASS	NO			K^+p
L3	NO			$\gamma\gamma$

The situation is getting more intriguing, as recently CLAS collaboration reported negative results on Θ^+ photoproduction off proton and deuteron with high statistics

V.Burkert, presented at LP2005, Uppsala, Sweden

LEPS collaboration reported the new evidence of the Θ^+ in $\gamma d \to \Theta^+ \Lambda^*(1520)$

N.Nakano, presented at QCD2005, Beijing, China

STAR collaboration observed the doubly charged exotic baryon in the pK^+ decay channel

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Therefore pentaquark existence is still under the question. and new experiments are needed to confirm or refute it.

Assumed properties of $\Theta^+(1540)$:

- It exists
- Mass 1540 MeV
- Width $\approx$ 1 MeV
- $J^P = \frac{1}{2}^+$ (Phase shift analysis, crucial for χSM)
- $I = 0$

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❖ HERA-B is a fixed target C, Ti, and W experiment at the 920 GeV proton storage ring of DESY

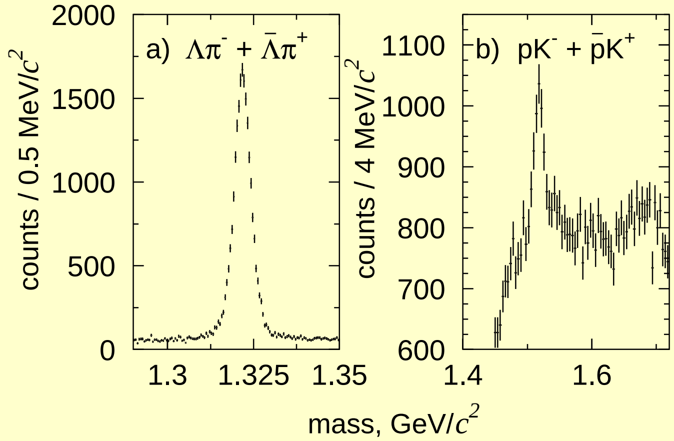

Figure 1: Signals obtained with the C target: a) $\Xi \to \Lambda\pi$ and b) $\Lambda(1520) \to NK$

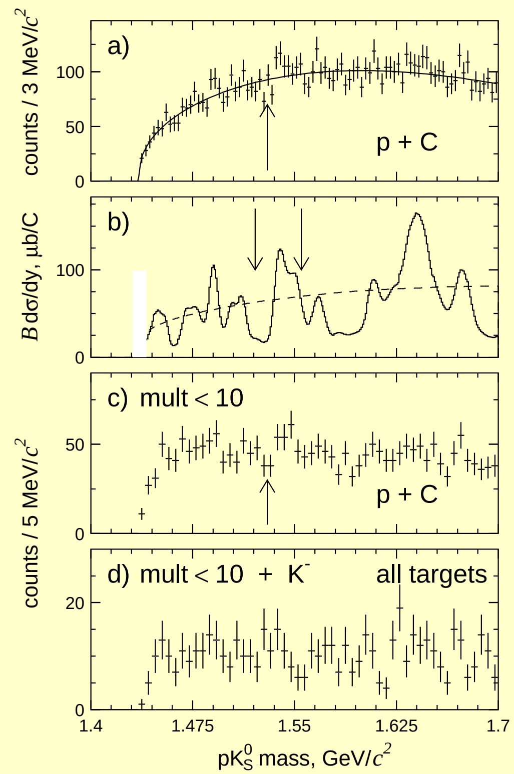

Figure 2: The pK_S^0 invariant mass distributions. Data from $p{+}C$ collisions

Recent IHEP result (SVD-2 detector) on $pA \to pK_S^0 X$ reaction with 70 GeV protons hep-ex/0509033:

- $M_\Theta = 1523 \pm 2(stat) \pm 3(syst)$ MeV, $\Gamma < 14$ MeV
- $\sigma \cdot \mathcal{B}R(\Theta^+ \to p\bar{K}^0) \sim 6$ μb (before was estimated as 30 μb)
- $\Lambda(1520)$ cross section for $x_F > 0$ is estimated to be 100-150 μb

Table 3: Upper limits on the relative yields of Θ^+ and Λ^* states at 95% CL

Experiment	Reaction	Limit	Comments
HERA-B	$pA \to K_S^0 pX$	$< 0.02 \times \Lambda^*$	mid-rapidity ($y_{cm} \approx 0$)
E690	$pp \to K_S^0 pX$	$< 0.005 \times \Lambda^*$	Central Collisions
CDF	$p\bar{p} \to K_S^0 pX$	$< 0.03 \times \Lambda^*$	
E690	$pp \to K_S^0 pX$	$< 0.005 \times \Lambda^*$	800 GeV/c, mid-rapidity
PHENIX	$Au + AU \to K^- \bar{n} X$	not given	
SVD-2	$pA \to pK_S^0 X$	$4 - 6\%$	70 $GeV/c,\ x_F > 0$

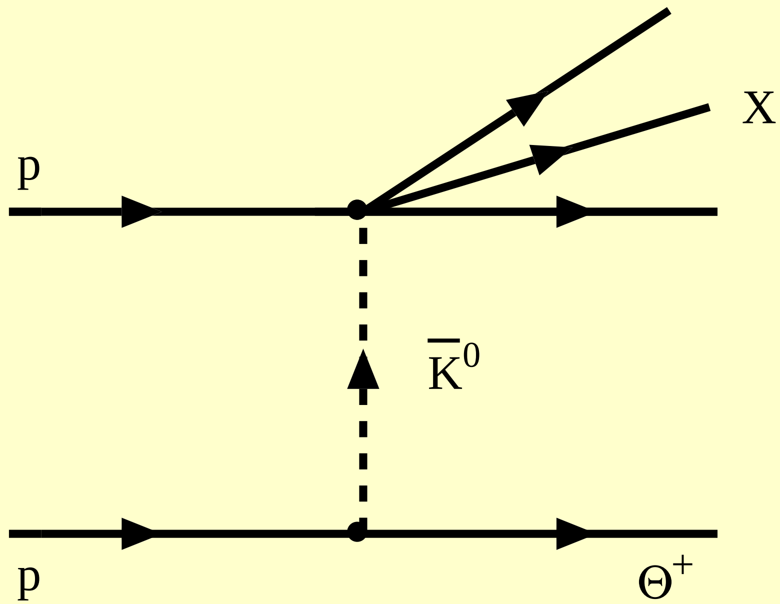

Figure 3: Θ^+ production in inclusive pp

Θ^+ production

The $KN\Theta^+$ vertex for $J^P(\Theta^+) = \frac{1}{2}^+$

$$\mathcal{L}_{KN\Theta} = iG_{KN\Theta}(K^\dagger \bar{\Theta}\gamma_5 N + \bar{N}\gamma_5 \Theta K).$$

The decay width $\Gamma_{\Theta \to KN}$ is

$$\Gamma_{\Theta \to KN} = \frac{G^2_{KN\Theta}}{2\pi} \frac{|\mathbf{p}|_K}{m_\Theta} (\sqrt{\mathbf{p}_K^2 + m_N^2} - m_N),$$

where $|\mathbf{p}_K| = 0.267$ GeV/c. $\Gamma_{\Theta \to KN} \propto p_K^3$ as $\mathbf{p}_K \to 0$

$$\frac{G^2_{\Theta KN}}{4\pi} = 0.16 \cdot \frac{\Gamma_{\Theta KN}}{1 \text{ MeV}},$$

$\Lambda(1520)$ production

The $KN\Lambda(1520)$ vertex is

$$\mathcal{L}_{KN\Lambda} = \frac{G_{KN\Lambda}}{m_K}\left(\bar{\Lambda}^\mu \gamma_5 N \partial_\mu K + \bar{N}\gamma_5 \Lambda^\mu \partial_\mu K^\dagger\right),$$

where Λ^μ is the vector spinor for the spin 3/2 particle. $\Lambda(1520)$ is treated relativistically using the Rarita-Schwinger vector-spinor formalism with the density matrix

$$L^{\mu\nu} = \frac{1}{4}(\hat{p}_\Lambda + m_\Lambda)\left[-g^{\mu\nu} + \frac{1}{3}\gamma^\mu\gamma^\nu + \frac{1}{3m_\Lambda}(\gamma^\mu p_\Lambda^\nu - \gamma^\nu p_\Lambda^\mu) + \frac{2}{3m_\Lambda} p_\Lambda^\mu p_\Lambda^\nu\right]$$

The coupling constant $\frac{G^2_{\Lambda NK}}{4\pi}$ is related to the total $\Lambda(1520)$ width by

$$\Gamma_{\Lambda(1520)} = \frac{G^2_{\Lambda NK}}{4\pi} \cdot \frac{\lambda^{3/2}(m_\Lambda^2, m_p^2, m_K^2)}{48 m_K^2 m_\Lambda^5}[(m_\Lambda - m_p)^2 - m_K^2]$$

Note that $\Gamma_{\Lambda(1520)} \propto p_K^5$ as should be for the D-wave $K^- N$ resonance.

Inclusive $pp \to \Theta^+ X$ cross section

$$\frac{d\sigma}{dx_F dk_\perp^2} = \frac{1}{4\pi}\frac{G^2_{\Theta K N}}{4\pi} \cdot \frac{1-x_F}{x_F} F_\Theta(x_F, k_\perp^2)\sigma_{\bar{K}^0 N}(s_1),$$

The $pp \to \Lambda(1520)X$ cross section

$$\frac{d\sigma}{dx_F dk_\perp^2} = \frac{1}{4\pi}\frac{G^2_{\Theta K N}}{4\pi} \cdot \frac{1-x_F}{x_F} F_\Lambda(x_F, k_\perp^2)\sigma_{K^- N}(s_1),$$

where

$$s_1 = (1 - x_F)s$$

The functions $F_\Theta(x_F, k_\perp^2)$ and $F_\Lambda(x_F, k_\perp^2)$ include the K^0 propagator and phenomenological form factor.

- The total cross sections $\sigma_{tot}(\bar{K}^0 p)$ and $\sigma_{tot}(K^- p)$ are approximately constant at the region $10\ \mathrm{GeV} < \sqrt{\mathrm{s}} < 100\ \mathrm{GeV}$.

$$\sigma_{tot}(\bar{K}^0 p) \ \sim \ \sigma_{tot}(K^- p) \ \sim 20\ \mathrm{mbarn}$$

$$\sigma(\Theta^+ X) \sim 0.8\ \mu\text{barn}, \quad \sigma(\Lambda(1520)^+ X) \sim 25\ \mu\text{barn}$$

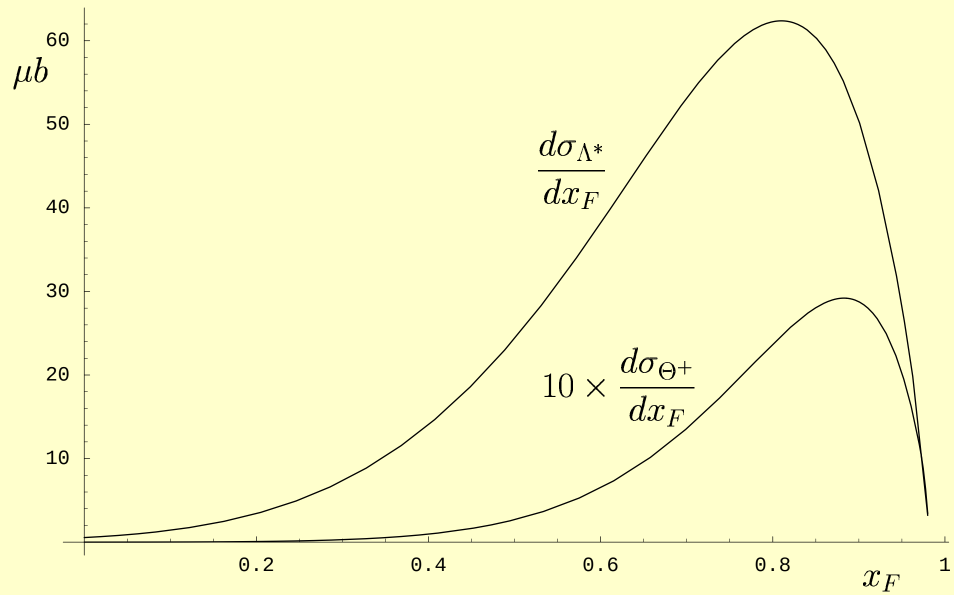

Figure 4: x_F dependence of inclusive cross sections

The ratio of $\Theta^+(1540)$ to $\Lambda(1520)$ production cross-sections:

$$\frac{\sigma_{\Theta^+(1530)}}{\sigma_{\Lambda(1520)}} \cdot \frac{\mathcal{B}(\Lambda(1520) \to pK^-)}{\mathcal{B}(\Theta^+(1530) \to pK_S^0)\mathcal{B}(K_S^0 \to \pi^+\pi^-)} \approx 4\%, \qquad (1)$$

where we have used PDG value $\mathcal{B}(\Lambda(1520) \to pK^-) = 45\%$.

Our conclusion is that inclusive Θ^+ production should be at the level of 1 μbarn at energies $\sqrt{s} \gtrsim 10$ GeV. This is lower than the preliminary cross section estimation, $\sigma \cdot \mathcal{B}(\Theta^+ \to p\bar{K}^0)$ for $x_F > 0$ SVD-2, but there is no serious disagreement considering the accuracy of both the our approach and experiment.

$< k_\perp^2 > \approx 0.25$ GeV^2 for Θ^+ and 0.5 GeV^2 for $\Lambda(1520)$

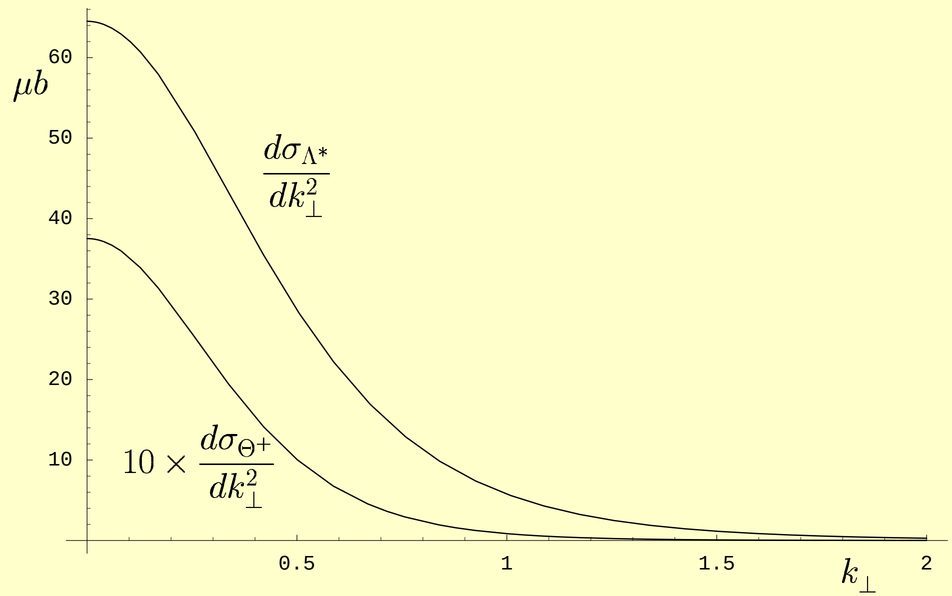

Figure 5: $k_\perp^2$ dependence of inclusive cross sections

CONCLUSIONS

- Our conclusion is that inclusive Θ^+ production should be at the level of 1 μbarn at energies $\sqrt{s} \gtrsim 10$ GeV.
- Accuracy of this prediction is at best within a factor 2
- Other production mechanisms: π exchange, K^* exchange, Regge phenomenology